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Water Quality of the River Damanganga (Gujarat)

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Water quality (*p*H, suspended solids, chlorides, DO, BOD, reactive and total phosphorus, nitrates and boron) of River Damanganga which receives 0.2 mld of industrial waste into its fresh water zone through Pimparia River and 3.7 mld in its tidal zone was studied at 10 stations along a 35 km stretch. Riverine flow decreased considerably in the premonsoon season and became almost negligible after April. Strong tidal effect with a water rise > 5.5 m was observed near the mouth of the river during spring tides which decreased to 3.5 m during neap tides. Tidal influence was weak at upstream stations and the industrial effluent was discharged in a zone where appreciable tidal influence occurs only during spring tides. The flood and ebb currents were fairly strong. Quality of water in the discharge zone deteriorated considerably after March (DO decreasing to about 1 mg/litre). High acid content of the effluent lowered *p*H of water. The discharge in the fresh water zone, presently did not affect the water quality adversely. The flushing time for the estuary was calculated to be 3 days, during February. The suspended load within the estuary was high. High concentrations of phosphate at some estuarine stations were associated with the waste water discharge.

River Damanganga in South Gujarat is a major source of fresh water for the industrial complexes at Vapi and Selvasa. The river joins the Arabian Sea near Daman and the intrusion of sea water within the estuary greatly varies depending on the riverine flow and the tidal stage. The entrance to the estuary is shallow due to heavy silting. This paper reports results of a detailed study carried out in the river Damanganga with special reference to the industrial waste water discharges.

Materials and Methods

Ten stations (Fig. 1) were fixed along the river (about 35 km). About 8 collections were made at each station for 7 months (Jan. to July 1977). A few measurements were also made in Feb. and March 1978. Tidal stations were operated during flood and ebb. Salinity over complete tidal cycles was measured at sts 7 to 10 for spring and neap tides during February. Cross-sectional profiles at nontidal stations were measured using fathometer (Model DE 719D). Ekman-Mertz type current meter was used for measuring current speed over complete tidal cycles during spring and neap tides at sts 8 and 10. When the depth was > 5 m, currents were measured at the surface, mid-depth and bottom. Surface currents were measured 1 m below the surface and bottom currents 1 m above the sediment. For shallow regions General Oceanics digital current meter was used. Only midstream currents were measured for tidal stations. Water level measurements were made by staff gauges (read every 30 min) at sts 5, 8 and 10.

Salinity was determined by argentometric titration[1]. Modified Winkler's method was employed for the estimation of dissolved oxygen (DO). For the determination of BOD, direct method was employed for samples having BOD < 4 mg/litre and unseeded dilution method[2] for samples having higher BOD. Industrial effluents were analysed using the seeded dilution method. In all cases samples were incubated at 20 ± 1°C in a BOD incubator for 5 days. Phosphate and nitrate were estimated by the procedures reported elsewhere[1]. Boron was determined by the curcumin procedure[3].

Results and Discussion

Industrial waste water discharge—River Damanganga receives waste water (3.9 mld) from the

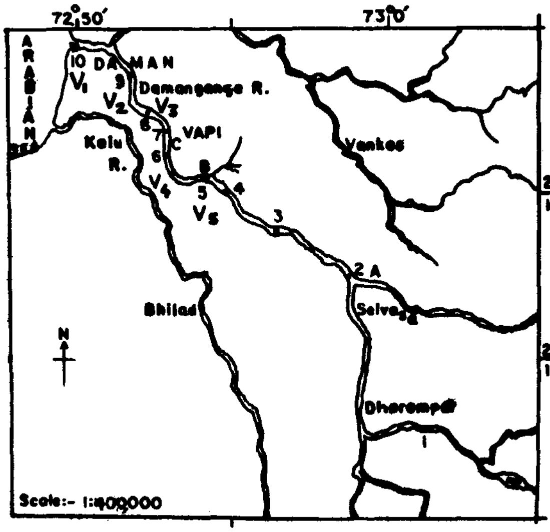

Fig. 1—Station locations

industrial estates located at Vapi and Selvasa and a few other industries at Vapi which lie outside GIDC area. Selvasa Industrial Estate discharges about 0.2 mld of liquid waste into the Pimparia River which drains in Damanganga River near st 2. A few industries located at Vapi discharge their effluents near st 7. These waste water streams were periodically sampled at locations A, B and C (Fig. 1). Although the waste water output from industrial estate at Selvasa has been expected to be only 0.2 mld, it gets diluted by the water from Pimparia River and the actual quantity measured at st A was between 0.63 and 1.88 mld (av. 0.96 mld; Table 1).

Tides and currents—Tides at the mouth of the estuary are mixed semidiurnal type. The rise in water level at st 10 during spring flood (1.7.77) was 5.6 m which declined to 3.6 m during the neap (9.6.77). The corresponding values at st 8 were 5.4 and 3.1 during the spring (30.6.77) and neap (16.6.77) tides respectively. Measurements near the st 5 where the GIDC effluent is discharged, indicated that some tidal influence was observed only during the spring tides. Therefore, the GIDC discharge is in the region of weak tidal influence and very little water for dilution is available during the dry season.

In the estuarine region, the currents were mainly tide induced during the dry season and varied with the tide. Typical plots of the instantaneous current speed are given in Fig. 2. Currents did not vary appreciably from surface to the bottom. The peak flood and ebb currents during the spring tide were fairly strong and decreased considerably during the neap period (Fig. 2). Currents were stronger at st 10 than at st 8. The peak flood and ebb speeds were observed after about 3 hr from the commencement of the tide and then decreased gradually. The current pattern indicated a swift water movement within the estuary and any effluent discharged beyond st 8 would mix well if discharged properly.

Flow characteristics—When the present survey commenced, the flow in the river was weak. The flow near sts 1, 3 and 5 was measured during March and April. At st 5 the measurements were also conducted during February. Current speed was measured along the sub-sections shown in Fig. 3. For sub-sections (a) to (e) of profile at st 1, the current speeds were 8.1, 18.2, 33.4, 24.2 and 14.5 cm/sec respectively and for sub-sections (a) to (c) of profile at st 3, the speeds were 14.6, 13.8 and 11.3 cm/sec respectively in March. Currents were measured at least thrice to compute the river flow. Current speed decreased considerably during April. Flow of 94.6 mld at st 1 during March, decreased to 57.3 mld in April. At st 3 the flow was only about 2 mld in April. This multifold decrease compared to st 1 was mainly due to storage of water along the river bed by putting temporary mud bunds. Water flowing over the Vapi weir was the major source of dilution for the GIDC effluent discharged near st 5. The river flow

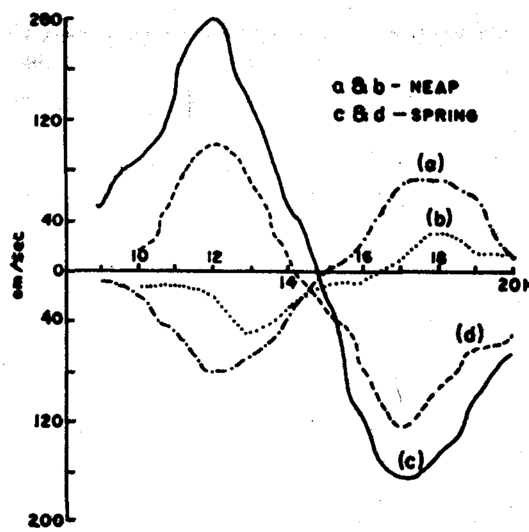

Fig. 2—Variation of current speed with time [(a) st 10, 9.6.77, neap; (b) st 8, 16.6.77, neap; (c) st 10, 1.7.77, spring; (d) st 8, 30.6.77, spring]

Table 1—Characteristics of Waste Discharges in the River Damanganga

Parameter	Discharge (A)			Discharge (B)			Discharge (C)		
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
Flow (mld)	1.88	0.63	0.96	3.83	1.90	2.74	0.35	0.3	0.31
Suspended solids (mg/l)	150	6	50	208	46	110	310	144	175
Chlorides (g/l)	0.7	0.2	0.4	5.2	1.2	4.8	6	1.1	4.6
pH	7.9	7.2	7.6	3.8	2.8	3.2	12.3	8.1	9.8
Dissolved oxygen (mg/l)	6.3	3.8	4.8	0.5	0	0	0	0	0
BOD (mg/l)	47.0	4.2	26.2	203	97	135	530	125	215
Total phosphorus (μg/1)	172	35	83	10,000	2300	4200	542	177	180
Sulphate (mg/l)	350	182	256	7,000	200	2300	1000	463	632
Phenolics (μg/l)	560	16	32	296	60	158	768	288	426
Oil and grease (mg/l)	18	6	16	640	0.8	21.3	—	—	—

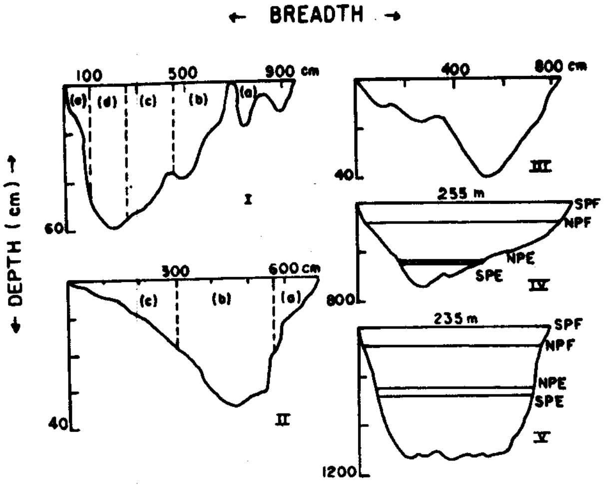

Fig. 3—Cross-sectional profiles [(I) st 1, (II) st 3, (III) st 5, (IV) st 8, (V) st 10; NP - neap, SP - spring, F - Flood, E - ebb]

which was 87 mld in early February decreased to 29 mld in March and there was practically no flow during April. Evidently, very little water for dilution was available during April to June, after which the monsoon flow begins.

Salinity—At nontidal stations, chlorinity generally increased from January to May (Fig. 4), perhaps due to the reduction in the flow and increased evaporation. In the estuarine region the salinity was influenced by the river discharge and tidal conditions. At st 8, the salinity increased from 20.5‰ during January to 34.8‰ just before the commencement of monsoon, after which it drastically decreased to < 0.2‰. Even at st 10, the salinity was of the same order during high riverine flow. Beyond st 8, the estuary has rocky outcrops which at several places trap saline flood water. Such pools often had high salinity (37-40‰).

Measurements over a tidal cycle at st 8 indicated progressive increase in salinity (Fig. 5). The surface salinity of about 25‰ at the ebb slack increased to 32‰ at the flood slack. The surface and bottom salinities greatly differed (Fig. 5) during the low tide but the difference decreased as the flood slack approached. This was due to the fresh water flow which formed a component of the surface layer. The vertical gradient at st 10 was not appreciable and the difference between the surface and bottom water was only about 1.6‰ at the ebb slack.

Flushing time—Flushing time for the estuary was calculated[4,5] on the basis of the data collected during spring and neap tides in February. The estuary was divided into 4 segments (Fig. 1). The distance between the segments V_1 and V_5 was 12.5 km. The average segment volume was calculated from the cross-sectional areas, the tidal ranges during spring and neap tides and the distances between the cross-sections. The surface and bottom salinities were measured over a

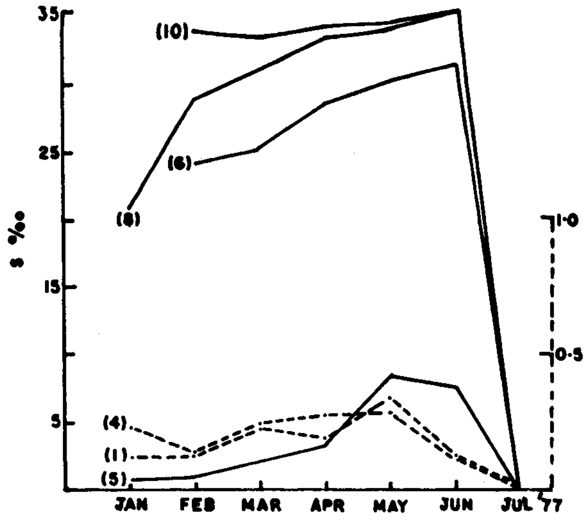

Fig. 4—Monthly salinity/chlorinity variation during flood tide at sts 1, 4, 5, 6, 8 and 10

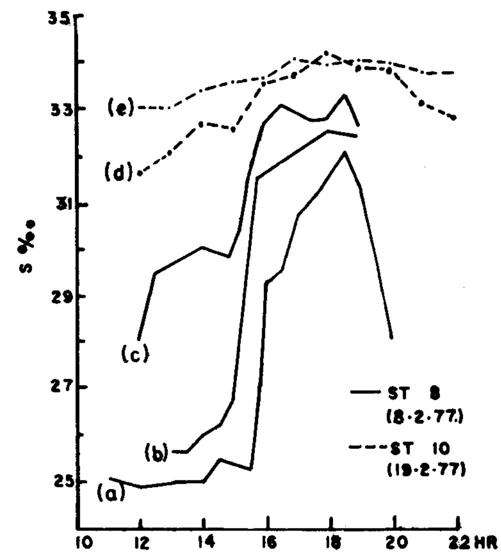

Fig. 5—Variation of salinity at sts 8 and 10 [(a) and (d) surface; (b) middle; (c) and (e) bottom]

tidal cycle for each segment during the spring and neap tides. The river flow was measured 4 times at hourly intervals near the Vapi weir for a 12 hr duration. The mean flow was calculated to be 87 mld. The chloride content of the bay water was obtained by collecting the samples about 1 km away from the mouth of the estuary. The average of 15 determinations was 18.4‰. Nearly 3 days were needed for the waste water discharged at location B to reach large scale dilution past the mouth of the estuary (Table 2). Again about 2 days would be required for the discharge at location C. Waste discharged into the estuary is, therefore, not completely carried to the sea by each ebbing tide.

Suspended load and light penetration—Mean suspended load at the fresh water stations varied in the

Table 2—Segment Volume, Chloride Content, Volume of Fresh Water and Flushing Time for the River Damanganga

Segment	Av. chlorides (mg/l)	Segment vol. ($m^3 \times 10^5$)	Vol. down stream ($m^3 \times 10^5$)	Av. chlorides downstream (mg/l)	Vol. of fresh water ($m^3 \times 10^4$)	Flushing time (days)
V_1 - V_2	18300	37.28	37.28	18300	2.04	0.2
V_2 - V_3	18000	17.22	54.50	18200	5.97	0.7
V_3 - V_4	16800	10.5	65.00	18000	14.23	1.6
V_4 - V_5	4500	1.46	66.46	17700	25.51	2.9

Table 3—Suspended Solids, *p*H, DO and BOD for the River Damanganga

St No	Suspended solids (mg/l)				*p*H			Dissolved oxygen (mg/l)				BOD (mg/l)			
	Max	Min	Mean	Monsoon	Max	Min	Monsoon	Max	Min	Mean	Monsoon	Max	Min	Mean	Monsoon
1	126	3	63	.538	8.1	7.7	7.6	10.8	6.7	8.7	7.2	3.8	0.8	2.1	2.4
2	145	41	91	—	8.9	7.5	—	9.9	8.6	9.3	—	7.8	3.4	6.2	—
3	115	38	75	761	9.1	8.4	7.6	11.7	9.0	10.5	8.5	5.5	2.7	4.2	1.2
4	74	21	52	460	8.8	7.8	—	10.3	6.7	9.2	—	4.5	1.0	2.7	—
5	135	26	90	332	7.1	4.8	7.7	9.4	0.4	3.5	6.7	68.0	9.4	40.6	1.0
6	180	50	115	—	8.4	7.4	—	8.4	4.6	6.9	—	4.6	2.3	3.5	—
7	155	34	103	—	8.6	8.1	—	5.2	3.1	3.8	—	24.0	14.6	18.4	—
8	144	46	88	353	8.2	7.8	7.6	7.8	5.7	6.9	7.4	0.7	8.5	2.8	1.1
9	277	91	163	—	8.3	7.6	—	7.5	6.9	7.2	—	4.2	2.3	3.2	—
10	231	59	135	325	8.3	7.6	7.6	7.4	5.2	6.5	6.5	2.3	1.1	1.6	1.9

range 52-91 mg/litre (Table 3). A definite increase observed in the estuarine zone is due to stirring up of sediments by strong tidal currents. Combined suspended load of about 350 kg/day through the discharge at locations B and C is negligible considering the high background levels of the estuary.

At nontidal stations the water was clear and transparent up to the bottom except at the deeper st 4 where the transparency measured by Secchi disc varied from 2 to 5 m. In the estuarine zone, visibility was relatively low (0.15 to 0.55 m) due to the high suspended load during flood and ebb tides. It increased marginally from 0.3 to 1.15 m during the slack period when the suspended load partly settled.

*p*H—The discharge at A had almost neutral *p*H. The GIDC effluent at B, however, had a *p*H in the range 2.8 to 3.8 (Table 1). The acid content of this outfall often decreased the *p*H of the receiving water at st 5 (Table 3). At st 6, however, the *p*H was normal indicating that the reduction of *p*H at st 5 was only a localised effect. The discharge at C was sometimes alkaline (Table 1) but the water at st 7 had normal *p*H (Table 3). This may be due to the greater dilution of the effluent and also due to the strong buffering capacity of sea water. Higher *p*H of the order of 9 (Table 3) was observed at some stations in the fresh water zone though the cause could not be identified.

DO and BOD—The discharge at A on an average added a BOD load of 25 kg/day to the river near st 2. Dye dispersion studies showed weak movement. The effluent, therefore, would remain trapped for a considerably long time in the 2 km stretch of the river basin. The water quality at st 2 as judged on the basis of DO and BOD values (9.3 and 6.2 mg/litre respectively) was satisfactory. The incoming waste water had DO ranging from 3.8 to 6.3 mg/litre, perhaps due to its mixing with the water from the Pimparia River, which helped in retaining a good water quality at st 2. It is evident from Fig. 1 that any effluent released beyond st 4 would be ultimately collected in the Vapi weir. Hence, any further increase in the waste water output as a result of commissioning of new industries will have to be carefully considered. The present data at st 4 (Table 3) are indicative of good water quality which should be maintained.

The waste water at B, which was devoid of DO added a BOD load of 360 kg/day (Table 1). This outfall is in the region of weak tidal influence and the fresh water overflow with high DO not only diluted the effluent but also carried it with the flow to the tidal zone. Evidently, substantial DO levels were observed at st 5 during February. The fresh water flow decreased considerably during subsequent months and the water quality of the river segment between sts 5 and 6 gradually deteriorated. Thus, the DO level fell from 9.4 mg/litre in February to about 1 mg/litre in April-May at st 5. The effluent was then seen collected in stagnant and stinking pools in between the rocks on the river bed. With the commencement of monsoon flow the conditions again improved and DO increased to 6.7 mg/litre in June.

Although the discharge at C was devoid of DO and added a BOD load of 65 kg/day, it did not severely affect the water quality at st 7 where DO was always > 3 mg/litre due to the sufficient amount of tidal water available. BOD was higher and often > 15 mg/litre.

Phosphates and nitrates—Low levels of phosphate and nitrate in the fresh water zone (Table 4) are as in an unpolluted tropical environment. At st 5, the concentration of phosphorus was high (av. 3117 and 3613 μg/litre for reactive and total phosphorus respectively) while, the nitrate concentrations were quite low which may result from industrial discharge. High concentration of phosphorus (4200 μg/litre) in the waste water discharge at B (Table 1) is responsible for increased levels at st 5. Influence of phosphorus content of the effluent was observed even at st 7 where though the levels were much lower, were comparatively higher than near the mouth of the estuary (Table 4). Since the flushing time is small the built-up of phosphate to levels to cause algal blooms is less likely. Also the levels of nitrates were low in the estuary (Table 4) and would, therefore, be the major limiting factor for the growth of algae.

Boron—Boron in the fresh water zone ranged from 0.02 to 0.07 mg/litre (Table 4) and is well within the limit prescribed for the use of water for irrigation. The content increased sharply in the estuarine zone and the observed levels were 0.15 to 3.57 mg/litre. Boron in sea water bears a relatively constant ratio (0.220-0.245) with chlorinity[6]. Limited data available suggest that its behaviour in the zone of estuarine mixing could be different[7]. During the present study B/Cl ratio was close to the sea water value at higher chlorinities but varied considerably (0.760-1.190) at chlorinites < 7‰ indicating that the behaviour of boron is nonconservative at low chlorinities in the estuary.

Light absorption studies—The absorption spectrum of the waste water released at B indicated a strong absorption around 600 nm. The absorbance of the filtered water from all stations was, therefore, measured at 600 nm with 5 cm cuvette. The effluent (Fig. 6) increased the absorbance of the receiving water at st 5. Also, the effluent could be distinctly traced even up to the sts 6 and 7, where the absorbance was higher than that observed at st 10. By comparing the absorbance values of the waste water with the value at st 6 it was concluded that at st 6 the effluent had achieved only 6 times dilution during April when measurements were made.

From the foregoing discussion it has been concluded that, the waste water discharge from the Selvasa industrial estate does not affect the water quality of the river water very much as far as the pollutants given in Table 1 are concerned. However, any further expansion of the estate, would require a very careful examination as the waste discharged will remain accumulated in the Vapi weir. The GIDC effluent is in the region of weak tidal zone and deteriorates the water quality of the river stretch down to st 7 during the dry

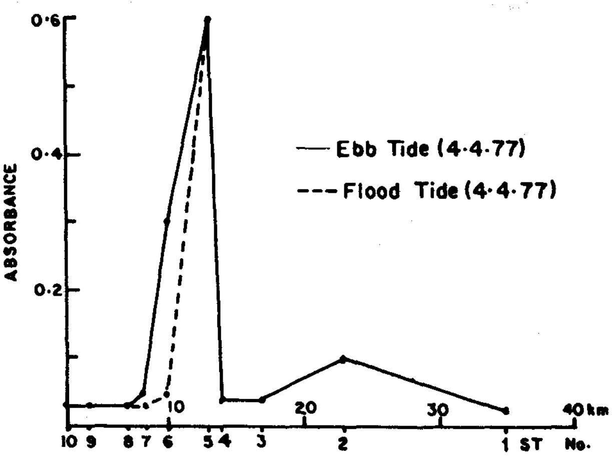

Fig. 6—Absorbance at 600 nm by water from different stations

Table 4—Reactive Phosphorus, Total Phosphorus, Nitrates and Boron for the River Damanganga

St No.	PO_4-P (reactive) (μg/l)			PO_4-P (total) (μg/l)			NO_3-N (μg/l)			Boron (mg/l)		
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
1	75	13	35	309	35	155	15	4	11	0.03	0.02	0.02
2	40	13	23	424	55	148	66	8	32	0.13	0.02	0.07
3	20	16	34	221	44	105	32	8	20	0.09	0.02	0.04
4	56	13	25	88	27	56	139	5	41	0.05	0.03	0.04
5	5061	772	3117	5740	2296	3616	298	19	170	0.25	0.09	0.15
6	330	210	262	830	380	536	477	26	172	3.41	1.5	2.23
7	423	215	335	775	625	697	41	39	40	3.32	2.52	2.96
8	346	89	170	672	216	330	162	8	62	4.76	2.75	3.57
9	102	80	91	369	123	226	116	·2	60	3.51	2.57	2.97
10	150	51	98	318	168	236	84	11	58	3.57	2.63	3.02

season. It is, therefore, advisable to discharge the effluent beyond st 8 so that it can easily be washed to the sea during the ebb tide.

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